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ARCTIC AND ANTARCTIC ACOUSTICS*

T. C. Poulter

Biological Sonar Laboratory
Stanford Research Institute
Menlo Park, California

ABSTRACT

The characteristics of sound transmission over snow-covered territory or in snow tunnels are discussed, along with work conducted in the Antarctic. Extensive recording under the ice of Weddell Seals in the Antarctic and under-ice recordings at Point Barrow of Arctic fur seals and other animals have been made and are discussed. In addition, information on the killer whales in captivity in Seattle provides a new insight into the differences in the sounds of male and female whales.

INTRODUCTION

An observing physicist does not have to be in the low temperatures of the polar regions for more than a short time before he will observe a number of acoustical phenomena that were not common to his experiences in lower latitudes.

ACOUSTIC AND EXPLOSIVE ABSORPTION IN ICE

One of these was first observed in the Antarctic in 1934 during the construction of a tunnel through the very porous, coarsely crystalline snow for communication during the winter night between the buildings in camp and the magnetic observatory. This 30-inch wide tunnel was constructed by cutting snow blocks from the solidified snow, leaving a trench about 30 inches wide and 4 feet deep. The blocks which were cut from this trench were laid up along the side of the trench to form the upper half of the walls of the tunnel, and large snow blocks were laid across the top. The tunnel, so constructed, rapidly drifted over and formed a very serviceable passageway.

With one man at each end of a 20-foot section of the completed tunnel, it was discovered that it was almost impossible for them to talk to each other. After experimenting for some time with the acoustical phenomena of this section of tunnel, they discovered that they could hear the sound of a working party using snow saws and digging in the hard snow with shovels, and also the noise of the snow crunching under their feet as they walked about. Upon investigating no one was even near, but upon stepping back into the tunnel, the sounds were unmistakable. A more careful inspection revealed that the noise was coming from a group of men who were digging in the snow to anchor a plane more than 200 yards away. This was very encouraging, for if the energy traveled that well through the snow, we should have no difficulty in getting some excellent seismic records. We did not know then what surprises awaited us when we tried our first seismic work.

Our first experimental explosive charge was a 1/2-pound stick of TNT placed 3 feet deep in a 3-inch-diameter hole in the hard snow, with snow lightly tamped over it. When attempting

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to fire the charge, the report was scarcely audible at a distance of 75 feet and no visible disturbance occurred at the surface. Upon inspection, to see if only the cap had fired, we found that the entire charge had detonated forming a spherical cavity about 10 inches in diameter. These experiments were repeated several times using both TNT and Trojan powder with the same results. The porous snow seems to serve as an idean condenser for the hot gases of the explosion.

On one occasion a 1/2-pound charge was placed 2-1/2 feet deep in a 3-inch hole in the bottom of a vertical shaft 4 feet square and 30 feet deep. A horizontal tunnel intersected this shaft 15 feet above its bottom. Two men, standing in this tunnel and adjacent to the vertical shaft, heard no sound when the charge was fired. Inspection showed that the charge had produced a cavity about 1 foot in diameter without cracking the snow of the bottom of the shaft.

Because of the very great absorption of energy in the immediate vicinity of a charge buried in the snow, an analysis was made to see how much of this damping could be attributed to thermal effects.

A mass of snow weighing 2154 g and having a density of 0.3, the measured density at this location, would occupy 7200 cc or would be a sphere having a diameter of 24 cm or about 9-1/2 inches. This corresponds very closely to the 10-inch diameter cavities observed. It is obvious, therefore, that no large portion of the water could have been vaporized since that would have required about 85 percent of the available heat energy.

A careful inspection of the snow surrounding the spherical cavities produced by such explosions revealed that there were tiny black particles from the charge as much as 2 feet away from the center of the charge and that the pores of the snow were not clogged, whereas in other places they had apparently been increased in size.

The volume of the gas produced by the detonation of 1/2 pound of TNT, when reduced to standard conditions, is 5.7 cubic feet. The maximum temperature in the center of the explosion probably will not exceed 2820°C. If all the gas were at this temperature and at one atmosphere, its volume would only be 22 cubic feet. This is the equivalent of the gas contained in a sphere of snow having a radius of 2.7 feet and a density of 0.3. Such a sphere has about twice the volume of a sphere having a radius of 2 feet or the distance that particles were driven out into the snow. The gas that penetrates the snow is no doubt cooled to nearly the snow temperature within a few milliseconds.

Many very unusual conditions present themselves for the study of the transmission of sound in the polar regions and particularly on any large flat ice surface. It is not uncommon to have almost perfectly still air with a flat snow surface extending for many miles and to have the snow surface covered with a few inches of freshly fallen snow or, if near the water, freshly formed frost an inch or more in thickness. Under such conditions and if the air temperature is uniform to a considerable height, one has the effect of an almost infinite space with no echoes or reverberations of any kind. The complete absence of all reflections of sound as one travels over such a surface is noticeable to the extent of being weird. If there are no obstructions for miles around, a man standing at a distance of 500 to 1000 feet will produce a sharp echo, and a mountain a tremendous rumble. The detonation of an explosive charge or rifle shot seems to consist of a single loud report followed immediately by almost complete silence.

If there is no loose snow or thick layer of frost on the surface, even a sastrugi surface of only a few inches in height is sufficient to produce a rumble following such a report. If, as is frequently the case, the surface is hard and cold still air near the surface is only a few hundred feet thick, above which there is a rapid temperature rise, the barking of dogs can be heard as far as 5 miles and a rifle shot 10 to 15 miles. The report of striking the snow with a shovel at a distance of 1000 or 2000 feet is frequently audible first through the snow and then through the air.

These phenomena are most striking during the later fall, winter, and early spring when the temperatures are well below zero. During a blizzard, however, when there is much snow in the air, sound transmission is very poor.

WEDDELL SEALS IN THE ANTARCTIC

The Weddell seal in the Antarctic is the tamest and probably the most vocal of all of the seals or sea lions, particularly under water. Their underwater signals like the fur seal, walrus, and several other species are quite similar to their signals in air, and are loud enough to be heard by the unaided ear if a person is standing on the 6-foot-thick ice above them.

They select for their rookeries places near pressure ice areas or small land or rock projections up through the ice where ice motion is continually forming cracks in the thick ice. In such areas they have ready access to the surface merely by keeping breathing holes open through the relatively thin ice, which forms in the cracks. Therefore there is considerable ice movement in the vicinity of the rookeries and hence much ice noise.

For this and other reasons we chose to make the underwater recordings of the Weddell seal far out on the bay ice where there was comparatively little relative motion and no open cracks.

A 12×24-foot recording shack with a 4-foot-square hole in its floor was built on skids so that it could be towed out on the ice by a small tractor.

A 4×6-foot hole was cut in the 6-foot thick ice and the hole in the floor of the shack was centered over this hole in the ice. Two hydrophone systems were suspended under the ice through this hole. One, a single Channel Industries Model C275, hydrophone suspended on its cable to a depth of 6 to 15 feet below the bottom of the ice and the other, a trainable directional hydrophone array consisting of 10 hydrophones arranged in a plane. This directional hydrophone array had a cluster of six hydrophones arranged in a 12-inch-diameter circle surrounded by a 4-foot triangle of hydrophones with a fourth one at the center of the triangle (Fig. 1). This hydrophone array was mounted 6 feet below the ice on a column connecting it to the control lever in the shack above. By means of this lever the array could be rotated through 360 degrees and tilted from horizontal to straight down. The control lever at all times pointed in the direction that the hydrophone was directed with scales for reading both angles (Fig. 2).

Even though the Weddell seals weigh as much as 1000 pounds, it is comparatively easy to put a net over them and load them into a sled and transport them to the shack out on the ice. If the sled containing the seal is backed up to the door of the shack and the sliding door in the end of the sled opened, the seal will usually head for the hole, particularly if it hears another seal in the hole or if a bucket of water is dipped up and poured into the hole so it can hear the water noise.

The shack was located 6 miles out on the bay ice far enough away from their normal breathing holes so that it had to use this hole for its breathing hole. We, therefore, had a captive animal completely at home in its natural habitat. Since this hole was larger, and did not freeze over due to the heat in the shack and was kept clear of floating ice by us, they seemed to prefer it to their normal breathing holes and would return to it even after cracks did develop nearby.

The 6-foot-thick, snow covered ice completely eliminated the wind and water noise and the 3 feet of loose ice crystals floating up against the bottom of the ice provided an excellent nonreflecting surface.

The water at this point was 2000-feet deep and the sound from the organisms on the bottom should be minimized. With such an isolated breathing hole, we felt that we could obtain recordings of only the one or two animals we had planted there, particularly with no other breathing holes within a radius of more than a mile and only three closer than the rookery at 6 miles. Sonograms of these recordings show that their signals will start out at a frequency of about 2 to 3 kc and a pulse rate as high as 200 pps and sweep down in frequency and pulse rate to 50 cps and a few seconds between pulses (Fig. 3). Such a series of pulses may continue for 30 or 40 seconds. There is an average of three signals on the recording at all times and a new signal is starting at an average rate of one every 3 seconds. From our observations of the

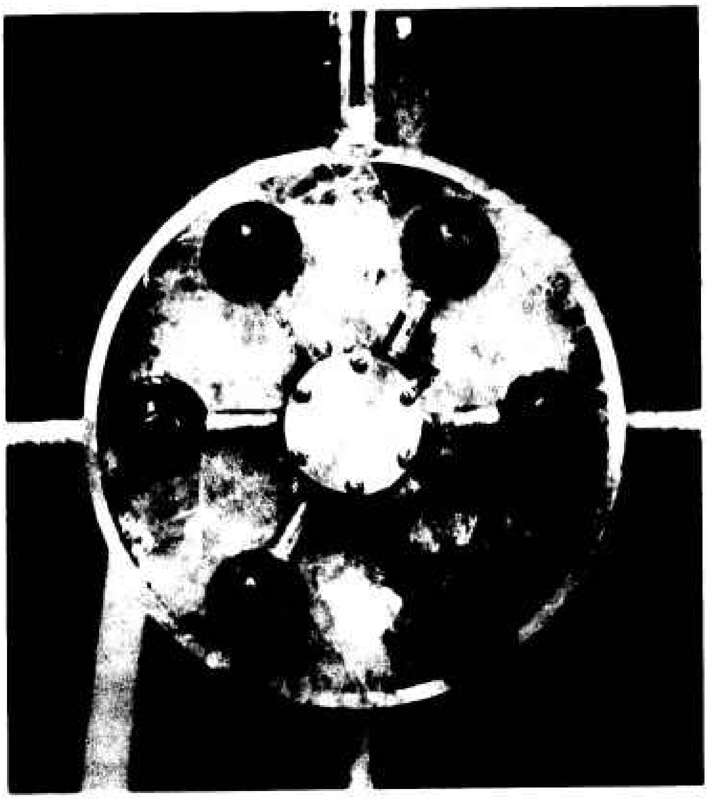
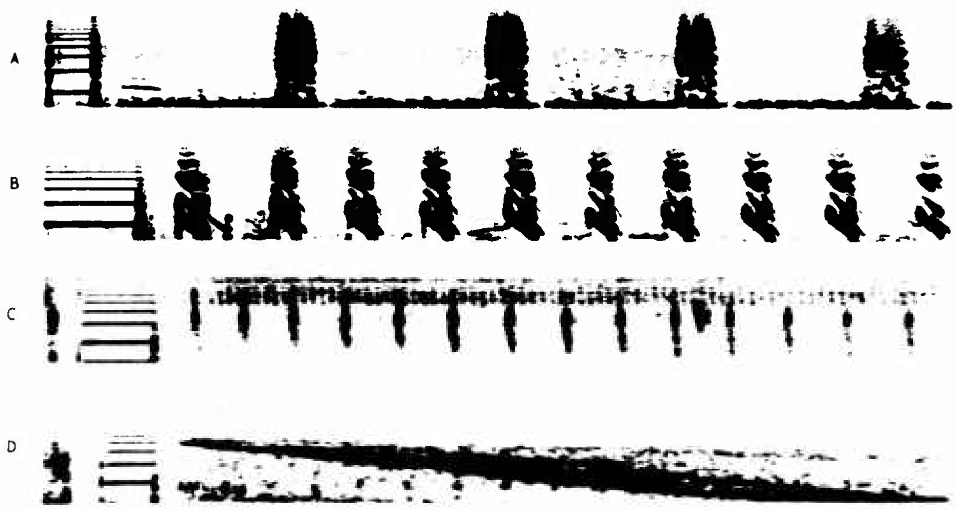
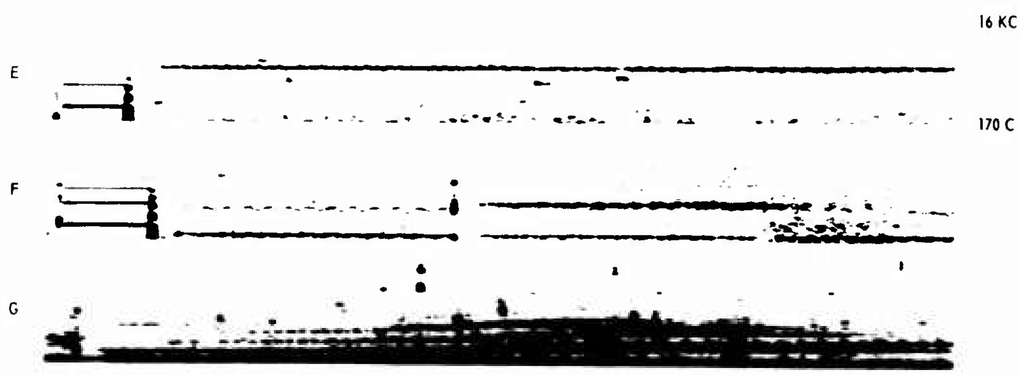


Fig. 1. Channel Industries Model C275 hydrophone array

Fig. 2. Control lever



Weddell seals – bull in air, cow in air, high and low rate clicks under the ice and high to low frequency sweep under the ice.



Leopard seal underwater high frequency signal, low frequency signal, and sweep up in frequency superimposed on low frequency continuous signal and clicks.

Fig. 3. Sonograms

frequency that the Weddell's signal by observing them from the shack and an under the ice observation chamber, we estimate that we must be recording the signals from at least 15 animals

Also, from our knowledge of the number and location of breathing holes in the area and the number of animals at each, we are convinced that we were recording them from a radius of 2 miles. In our recent studies of the killer whale, we have made recordings from a distance of 2 to 3 miles.

One of the most common errors in the recording of underwater signals is the limited frequency range of the recording equipment. The same signal of some animals recorded with upper frequency limits of 15, 20, and 100 kc will frequently produce sonograms which apparently have little in common.

SEX DETERMINATION BY SONOGRAM ANALYSIS

We have some 38,000 feet of magnetic tape of killer whale recordings taken in the Antarctic, Atlantic, and North Pacific as well as the captive killer whale, "Namu," at Seattle. We

find that it is possible to determine the sex of the killer whale from an inspection of sonograms of their signals, and with a little practice one can learn to recognize the difference between some of the calls of the males and females. We believe this is also true of the Weddell in the Antarctic, and we have shown it to be true of the Arctic fur seal. We spent the last half of July, 1965, recording the underwater signals of the northern fur seal in the waters adjacent to St. Paul Island in the Pribilof Islands. This is based not only upon the general character of the sonograms but the general frequency of the signal and the rate at which the clicks occur, which go to make up what appears to the ear to be a continuous signal. In the male, this rate may be as low as 8 per second or as high as 32 per second whereas for the females it may range from a low of 30 per second to a high of 60 per second and we have not yet resolved some of the highest ones.

We are presently scheduled to go to Point Barrow before the ice breaks up in the spring of 1966, probably late March or April, to make underwater recordings of the ringed seal, bearded seal, and any other species of seals or whales that may accommodate us.

During our recent recordings of the two killer whales in Seattle, we used an array of three hydrophones recorded on three channels with a fourth channel for a running commentary. By means of triangulations from this tape, combined with the running commentary which gave the relative positions of the two animals, it was possible to determine which animal produced each signal.

While at Point Barrow we plan to mount an array of four hydrophones in holes in the ice from which we believe we can simultaneously track all animals within our recording range.

ACKNOWLEDGMENT

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Appendix A

RECORDING EQUIPMENT

Large Sangamo 4700 is a seven channel record, reproduce unit having switchable speeds from 15/16 to 120 inches per second and a servo drive which will compensate for fluctuations in tape speed on the recording unit by means of an accurately controlled 100-kc signal on one channel.

The Pemco is the small four channel Model 101 portable unit together with the power supply and hydrophone and has a flat frequency response out to 100 kc at a tape speed of 30 inches per second and 50 kc at a tape speed of 15 inches per second.

A two channel Vega record reproduce unit has tape speeds ranging from 2.89 inches per second to 60 inches per second and a frequency response up to 120 kc at the higher tape speed was designed specifically for our use.

In addition to these we have a number of single channel audio frequency tape recorders.

Appendix B

ANALYSIS EQUIPMENT

Kay Electric Company Model 606A Sonograph

Minneapolis-Honeywell Model 906C-169X00H, 14 Channel Visicorder

Quan-Tech Laboratories Model 303 Wave Analyzer

30-channel bank of bandpass harmonic filters ±5% in 150 cycle steps

30-channel bank of bandpass harmonic filters ±1% in 150 cycle steps

24-channel oscillograph

36-channel oscillograph

Sound level measuring equipment plus other electronic and acoustical equipment, extensive hydrophones, transducers, speakers, and related equipment.